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A PRELIMINARY GLOBAL OCEANIC CLOUD CLIMATOLOGY FROM SATELLITE ALBEDO OBSERVATIONS

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Abstract. A pilot study has lead to the establishment of a preliminary predictive relationship for cloud amount as a function of satellite observed system albedo. The United States Air Force 3D-nephanalysis cloud archive is used as the source of cloud data and is compared with monthly mean system albedo values calculated by NOAA/NESS from the NOAA satellite scanning radiometer data at a resolution of 2.5° by 2.5°. The predictive relationship is applied to ocean areas to produce new global oceanic cloud climatologies.

1. Introduction

Global estimates of cloud amount are vital for meteorology, remote sensing, and climate modeling. Approximately 50% of the earth's surface is cloud covered. The location and nature of these clouds is of predominant importance in determining the radiation budget at the top of the atmosphere and at the surface. Clouds modify both the system albedo by their highly reflective nature and the atmospheric 'greenhouse effect' due to the absorption of terrestrial thermal infra-red radiation by both water vapor and liquid water.

Recent theoretical and empirical investigations [Schneider, 1972; Ohring and Clapp, 1980; Hartmann and Short, 1980; Ohring et al., 1981] indicate that net radiation is sensitive to cloud amount and that the 'albedo effect' of clouds predominates over the 'greenhouse effect.' Thus an increase in present cloud amount would reduce net radiation and lead to a cooling of the earth. These results emphasize the needs for a reliable global scale cloud archive.

An agreed cloud data set is a fundamental requirement as input for some climate models and for comparison with model predicted clouds. The global distribution of cloudiness is required to develop meaningful parameterizations between cloudiness and large-scale atmospheric variables (e.g., relative humidity, vertical velocity). Additionally observing and archiving cloud information would allow monitoring of climatic variability and potentially provide an early warning system for climatic changes. Such climatic monitoring would require very much more accuracy than is currently possible because the year to year change in cloud cover is quite small.

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Avaste et al. [1979] suggested that cloud amount can be estimated from the radiation budget components, assuming a linear relationship between cloud and system albedo, using the radiation budget archives to rederive cloud amount. This paper examines the relationship between the system albedo (derived from NOAA scanning radiometers) over oceanic areas and the 3D-nephanalysis total cloud amount data. (A description of the two data sets can be found in Winston et al. [1979] and Fye [1978] respectively). A predictive relationship is established from which a new oceanic global cloud climatology has been derived.

The most widely accepted cloud climatology appears to be that of London [1957]. This provides cloud type, height, and total cloud cover as a function of latitude for the northern hemisphere. This climatology was derived prior to satellite measurements and is, therefore, based on conventional surface observations. The oceanic cloud data are particularly uncertain. More recent global scale cloud climatologies based on satellite data include Clapp [1964], Sadler [1969], and Miller and Feddes [1971]. Examples of recent cloud climatologies based on surface observations are Hastenrath and Lamb [1977], for the tropical Atlantic and eastern Pacific oceans, and Berlyand and Strokina [1980] for the globe. (Berlyand and Strokina [1980] also incorporate satellite observations on a limited basis). However, these climatologies either contain little information on interannual variations or are limited to brief periods of time and therefore possibly unrepresentative.

2. Data Sources

Earth Radiation Budget System Albedo Data

The ERB data are available as monthly means on a 2.5° latitude-longitude grid from June 1974 to February 1978. The ERB parameters were evaluated from data from a series of NOAA satellites [Winston et al., 1979]. System albedo was determined by NOAA-NESS from the scanning radiometer visible channel data, assuming reflectance in the 0.5-0.7 μm region to be a good estimate of the full spectral reflectance, also assuming that the observed reflectance is isotropic and independent of solar zenith angle, that there is no diurnal variation of the reflecting surface and that the solar constant is known. The diurnal assumption is common to all estimates of reflected energy based on polar-orbiting satellites. One daytime observ-

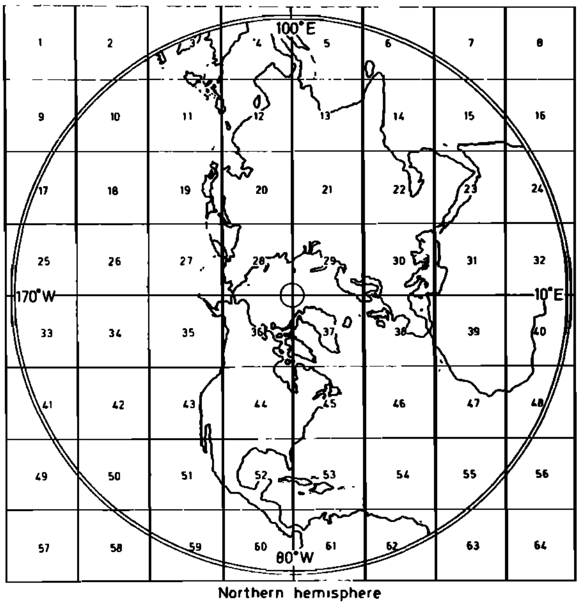

Fig. 1. The 3D-nephanalysis box areas for the northern hemisphere [after Fye, 1978].

ation at approximately 0900 LST is available. Operational processing at NESS 'normalized' the visible observation by dividing by cos z, where z is the solar zenith angle.

Due to the lack of on-board calibration of the visible radiometers, a systematic decrease in albedo has been observed over the entire data record (1% per year [Winston et al., 1979]). Errors in operational data processing procedures occurred during 1976, producing low, erroneous albedoes. This problem was most serious at latitudes poleward of 40° south.

3D-Nephanalysis Total Cloud Amount Data

The sole current global cloud assessment system for realtime meteorological forecasting is the 3D-nephanalysis produced by the United States Air Force. The 3D-nephanalysis uses data related to cloudiness from surface, radiosonde, aircraft and satellite observations [Fye, 1978]. Defense Meteorological Satellite Program (DMSP) data provide the majority of the satellite data input into the 3D-nephanalysis. DMSP observations are made at near local noon and midnight, and at dawn and dusk. Two spectral bands of data are available, visible (0.4-1.1 μm) and infrared (8-13 μm) (changed to 10.5-12.5 μm after June 1979). The 3D-nephanalysis cloud determination algorithm uses a threshold technique dependent upon both infra-red and visible signals and their variabilities. Unfortunately it is difficult to assess independently the accuracy of the 3D-nephanalysis since all conventional sources of cloud data are used [Henderson-Sellers et al., 1981] and the mode of incorporation has changed over the lifetime of the archive. 'Overall, the monthly mean 3D-nephanalysis cloud amounts are likely to be the best global data set currently available and certainly a step beyond the 25 year old London monthly zonal mean climatology' [Gordon and Hovanec, 1981, p. 165].

The horizontal resolution of the 3D-nephanalysis is approximately a 46 km grid (gridding is actually undertaken in 25 nautical mile increments). The data array is for a 64 x 64 grid for each of the 128 boxes covering the globe (Figure 1). The 3D-nephanalysis total cloud amount data have been used for this analysis, although a variety of cloud parameters are archived.

The 3D-nephanalysis is produced every 3 hours, while the system albedo data are only available as monthly means for a 2.5° latitude-longitude grid. Therefore, to provide comparable data sets the cloud amount data are summarized into monthly mean values on a 2.5° latitude-longitude grid. The problems and assumptions involved in achieving this have been discussed by Henderson-Sellers et al. [1981].

3. System Albedo and Cloud Amount Data

Concurrent 3D-nephanalysis total cloud amount and system albedo data have been analyzed for

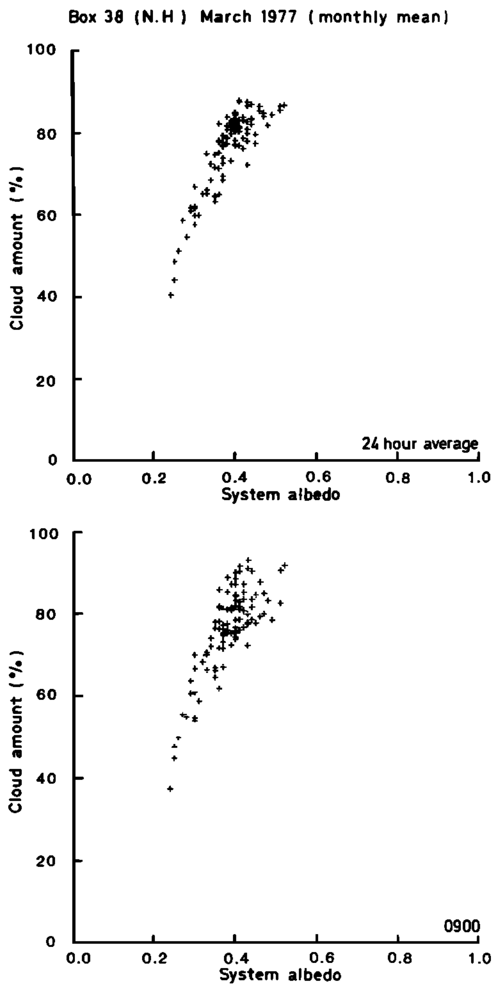

Fig. 2a

Fig. 2. Scattergraph of mean monthly system albedo (x axis) and mean monthly cloud amount (y axis) for 24 hours (upper) and 0900 hours (lower) for oceanic areas on a 2.5° by 2.5° grid. (a) Box 38 March 1977; (b) box 38 June 1977; (c) box 38 September 1977; (d) box 38 December 1977.

the 3D-nephanalysis boxes 37, 38, 39, and 47, March 1977, and box 38 June 1977, September 1977, and December 1977. The box areas are indicated in Figure 1. The immense volume of data processing required to analyze the 3D-nephanalysis cloud amount data makes a larger-scale study of the cloud amount itself prohibitive. The data processed here are adequate to permit both calculation of a latitudinal cross section of cloud regimes, and an examination of seasonal variations over box 38. Some of the boxes analyzed were selected because of the high density of surface stations they contained (e.g., box 38). Since the scheme described relates satellite observed albedo to cloud amount it was important to include cloud amount data that was not itself solely determined from satellite radiance measurements.

The relationship between mean monthly system albedo and cloud amount data for oceanic areas only has been examined. Over land surfaces, especially with high surface albedoes (ice, snow, desert), interpretation and identification of such a relationship is more difficult, requiring a detailed knowledge of the surface albedo values and their variability. Figures 2a to 2d depict the scattergraphs of mean monthly system albedo and cloud amount for ocean

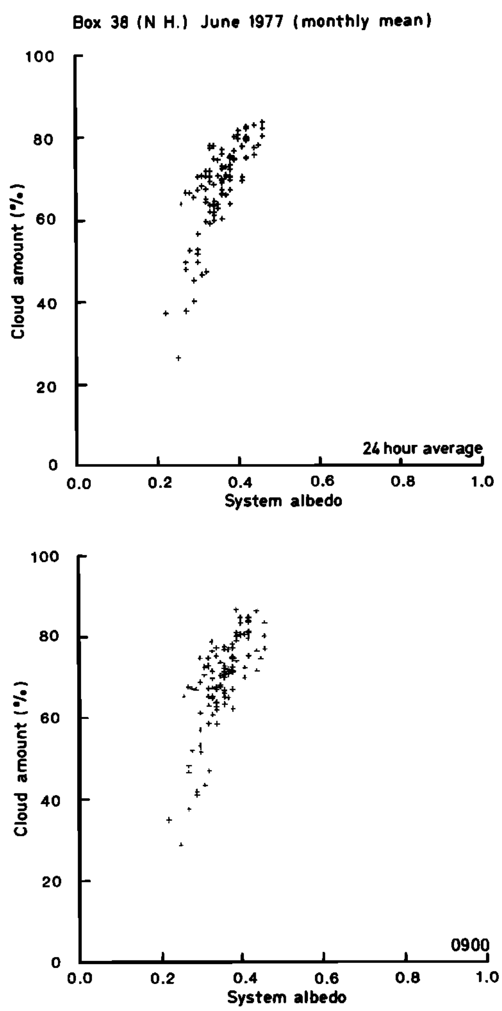

Fig. 2b

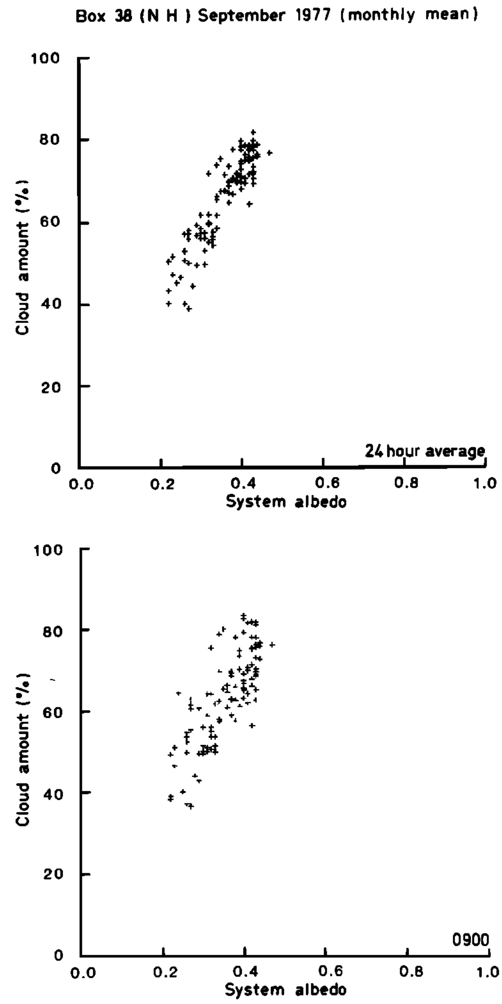

Fig. 2c

regions on the 2.5° by 2.5° grid. The graphs suggest a possible relationship between the variables. The relatively high cloud amounts in December may either represent values nearing the limits of the applicable range of a relationship established concurrently with the other months or may form an individual distribution. Below it is suggested that the former proposition is the more likely. Comparison of upper and lower graphs in Figure 2 shows that mean diurnal monthly cloud amount and 0900 mean monthly cloud amount have similar functional dependencies upon the system albedo.

Seasonal Variation in the Relationship Between Cloud Amount and System Albedo

In this preliminary investigation, data are examined to assess seasonal variations over box 38 only. Cloud type and cloud amount will vary seasonally over a mid-latitude area such as box 38. Here, the possible seasonal variability of the relationship between albedo and cloud amount is examined by comparing box 38 data with data from boxes 37, 38, 39, and 47 (a latitudinal cross section) for March 1977. Figure 3 shows these data plotted together with data from box 38 for June 1977 (Figure 3a), September 1977

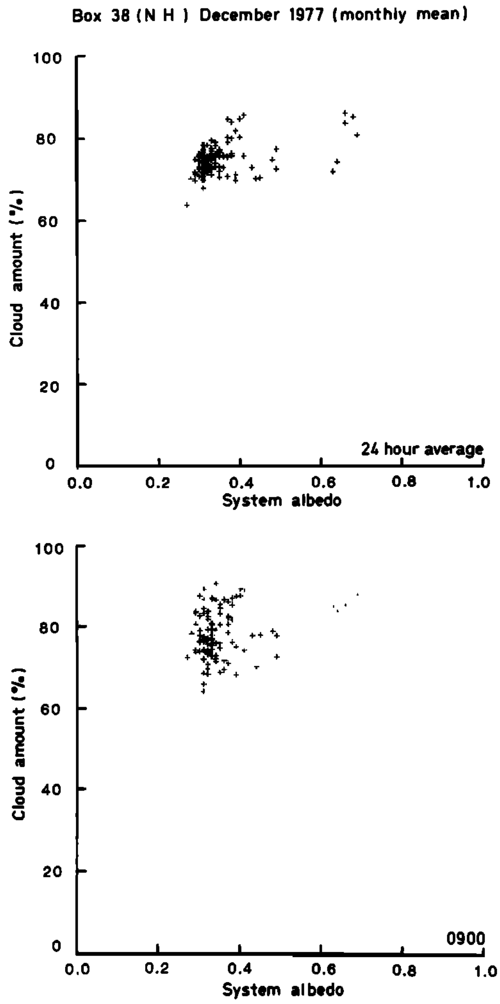

Fig. 2d

(Figure 3b), and December 1977 (Figure 3c). In all cases it is readily observed that the box 38 values appear to lie within the ranges of all the March 1977 data, supporting the view that there is no marked seasonality in the relationship. Later in the section this is derived as a seasonally independent formulation. The greatest range of system albedo is associated with the high percentage cloud amounts observed during December 1977 (Figure 2d and 3c). In such situations, a second parameter, such as cloud type (cloud albedo), appears to have a significant influence on the system albedo.

A predictive relationship between cloud amount and system albedo can be determined by regression techniques by using all the March 1977 data together with the three additional seasons of box 38 (1977). A linear regression, as suggested by Avaste et al. [1979] between system albedo, A, and cloud amount, N, gives

$$N = 137.45 A + 18.51 \tag{1}$$

where N is the percentage mean diurnal monthly cloud amount and A is the fractional mean monthly system albedo. This produces a cloud albedo of 0.59 and a surface albedo of -0.13 (coefficient of determination =0.78); i.e.,

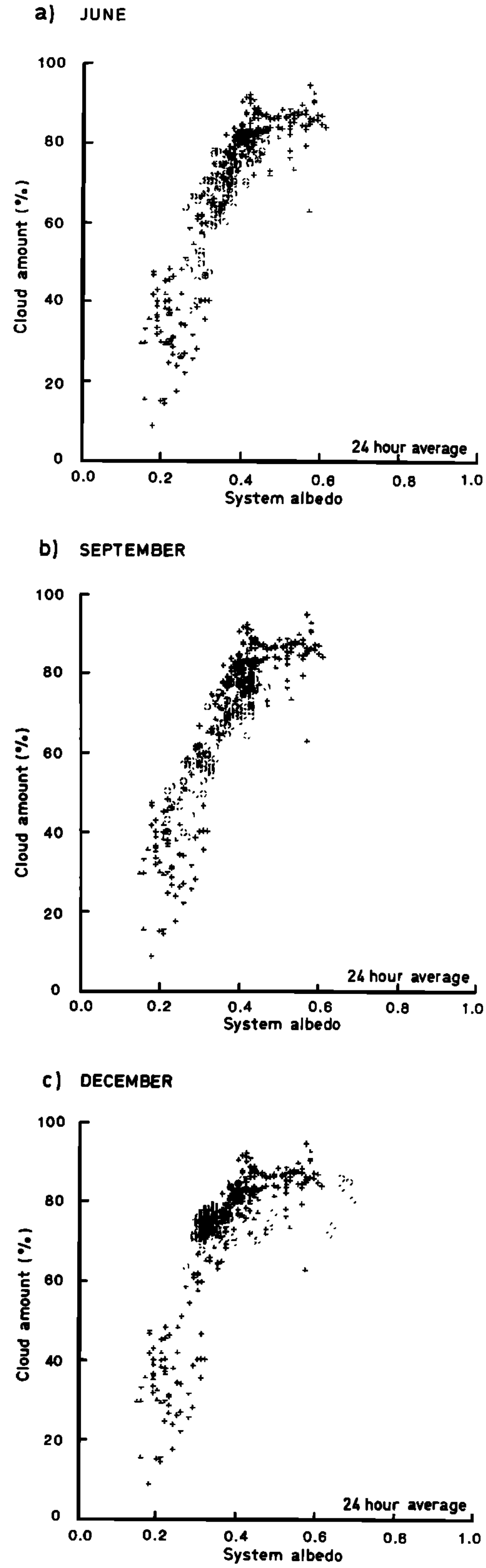

Fig. 3. Scattergraphs of mean monthly system albedo (x axis) and mean cloud amount (y axis) for ocean regions at 2.5° resolution. On each graph crosses indicate values for boxes 37, 38, 39, and 47 March 1977, while open circles indicate (a) box 38 June 1977, (b) box 38 September 1977 (c) box 38 December 1977.

extrapolation to zero cloud amount gives rise to a negative surface albedo. Further examination of the scattergraphs (Figures 2 and 3) suggests a nonlinear relationship between system albedo and cloud amount. Utilizing a logarithmic transform on the system albedo data produces more realistic surface albedo values. The regression equation is now

$$N=123.93\ (\log_{10} A) + 124.97 \qquad (2)$$

This produces a cloud albedo of 0.62 and a surface albedo of 0.09 (coefficient of determination = 0.85). The cloud albedo value compares favourably with the range of cloud albedo as measured by Stephens et al. [1978] (0.495 to 0.746). The surface albedo value is consistent with the oceanic surface albedo given by Hummel and Reck [1979] and Cogley [1979]. For a latitudinal cross section from 10° to 50°, the surface albedo would be 0.078 [Hummel and Reck, 1979] and 0.079 [Cogley, 1979]. Incidentally, the coefficient of determination is also higher than for the linear fit. A measure of the seasonal range in the regression equation is shown in Table 1 in which the parameters in equation (2) are listed together with the coefficient of determination for the four cases: all data March 1977 and the three cases shown in Figure 3. It must be noted that this range is for box 38 and for only 1 year data.

Avaste et al. [1979] compared an 8 year average (1965-1972) of Sadler's [1969] cloud amount data with the NOAA scanning radiometer data for June 1974 to February 1978. No time overlap occurred between the data sets. Their results are shown in comparison with the regression equation (2) obtained by using the NOAA scanning radiometer data and the 3D-neph-analysis cloud amount data (Figure 4). The excellent agreement between the data sets confirms the validity of using archived system albedo data to redefine cloud amount.

The scattergraphs of values used to produce the predictive relationship (Figures 2 and 3) illustrate the level of appropriateness of the cloud amount estimates. At low cloud amounts

TABLE 1. Regression Equation Parameters C_1 and C_2 from Equation (2) in which the cloud amount, N, is Related to the System Albedo A in the Form $N = C_1 (\log_{10} A) + C_2$

	March	June	September	December
C_1	131.21	138.23	116.38	21.44
C_2	131.04	130.99	118.55	84.75
coefficient of determination	0.89	0.79	0.90	0.45

The values of C_1 and C_2 and the coefficients of determination are listed for (1) March 1977 box 38, (2) June 1977 box 38, (3) September 1977 box 38, and (4) December 1977 box 38 - (cf Figure 2).

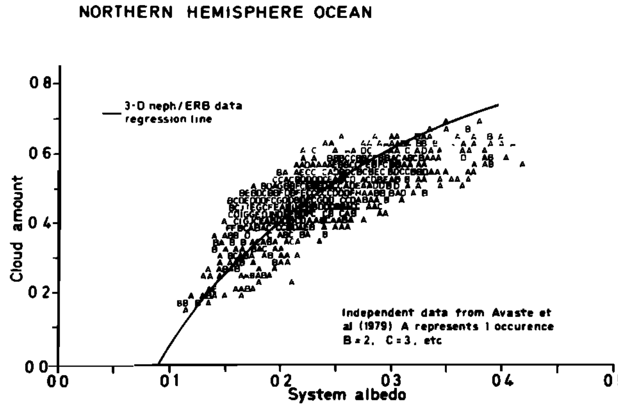

Fig. 4. Scattergraph of scanning radiometer system albedo data (x axis) and Sadler's [1969] cloud amount data (y axis) [from Avaste et al., 1979] with the regression formula derived here (equation (2)).

the relationship is well defined, as the system albedo tends toward the surface albedo. The larger spread for December (Figure 3c) reflects the high cloud amounts occuring over box 38 during this season (see also Figure 2d). As the cloud coverage increases the effect of cloud type and its associated cloud albedo increasingly dominates the system albedo. The wide range of values indicates the large variations occuring in cloud albedo and also, probably, in cloud type. Therefore, estimates of low cloud amount are likely to be more accurate than those of high cloud amounts.

4. System Albedo and 0900 Mean Monthly Cloud Amount Data

The satellite data used to evaluate system albedo are for approximately 0900 local time. In the previous section, the system albedo data have been compared with mean diurnal cloud amount. The strongest relationship between system albedo and cloud amount would be expected to occur by using the 0900 mean monthly cloud amount. The lower graphs in Figure 2 show the relationship between the 0900 mean monthly cloud amount and system albedo for the boxes and months discussed previously. A separate analysis shows that a diurnal curve in total cloud amount is present for all boxes though the signal is a function of latitude and geographical location. (The authors have presented preliminary analysis of diurnal data derived from the 3D-nephanalysis to the ISCCP workshop meeting in Ottawa. (See Nature, 298, 419, 1982.) Final results will be published in due course.) Typically, the range in the monthly averaged diurnal curve in box 38 does not exceed 15-20%. The difference between the 0900 hour and the mean diurnal cloud amount was found to be less than 2% in March 1977 for boxes 36, 37, and 38.

Using the 0900 mean monthly cloud amount reduces the coefficient of determination in the regression. Variation in the relationship between system albedo and mean diurnal cloud amount cf mean 0900 cloud amount reflects partially a geographically varying diurnal cloud signal. In some regions, the 0900 cloud amount observation is representative of the mean diurnal cloud amount [Wanless, 1979], and in these locations the choice of 0900 or mean diurnal is unimportant. The difference may also be indicative of the time lag of information flow into the 3D-nephanalysis. The 0900 3D-nephanalysis data set will not necessarily incorporate 0900 surface and satellite observations, due to the transmission time-lag into the archiving system. This time-lag rarely exceeds $1\frac{1}{2}$ hours [Fye, 1978; U.S.A.F. personnel, personal communication, 1982].

The predictive relationship computed by using the 0900 cloud amount observation is almost identical to that computed for the diurnal average (using a log transform)

$$N_{09} = 122.75\ (\log_{10} A) + 124.88 \qquad (3)$$

where N_{09} is the 0900 mean monthly cloud amount. This results in a cloud albedo of 0.62 and a surface albedo of 0.09 (coefficient of determination = 0.78).

The relationship between the mean diurnal monthly cloud amount and system albedo (equation (2)) is similar to the 0900 mean monthly cloud amount and system albedo relationship (equation (3)). The most appropriate function by which cloud amount can be predicted by using the system albedo data needs to be selected.

If the 0900 mean monthly cloud amount only were to be used, the derived function would be appropriate only for use with 0900 satellite data. We suggest however, that it is preferable to utilize the daily mean monthly cloud amount data for two reasons. First, the 3D-nephanalysis 0900 cloud amount observations are not as well focused in time as the archive structure suggests [Fye, 1978]. Second, there are other factors that could be included in a fuller predictive equation between system albedo and cloud amount (e.g., cloud type, solar angle, and underlying oceanic conditions). The importance of these secondary factors varies as a function of time. Including all the available data produces a more widely acceptable and applicable predictive relationship.

5. A New Oceanic Global Cloud Climatology

The predictive relationship given in equation (2) has been used to establish a new oceanic global cloud climatology for three years (Figure 5). Figure 5c, for example, shows the annually averaged cloud cover for 1977. The annually averaged values were derived by applying the regression formula (equation (2)) to the annually averaged albedo data. There appears to be overall agreement in respect of the gross features and magnitude of cloud amount with the satellite derived cloud cover maps of Clapp [1964] and Sadler [1969]; for example, the ITCZ and areas of persistent stratus cloud in the Pacific Ocean. However, the estimates of cloud amount are generally lower than the cloud amount data of Hastenrath and Lamb [1977] (tropical Atlantic and eastern Pacific oceans) and Berlyand and Strokina [1980]. Both these data sets are based on surface, daytime observations. Berlyand and Strokina [1980] suggest that as minimum cloud amount occurs at night, the effect of using only daytime observations in their calculations is to overestimate the cloud amount.

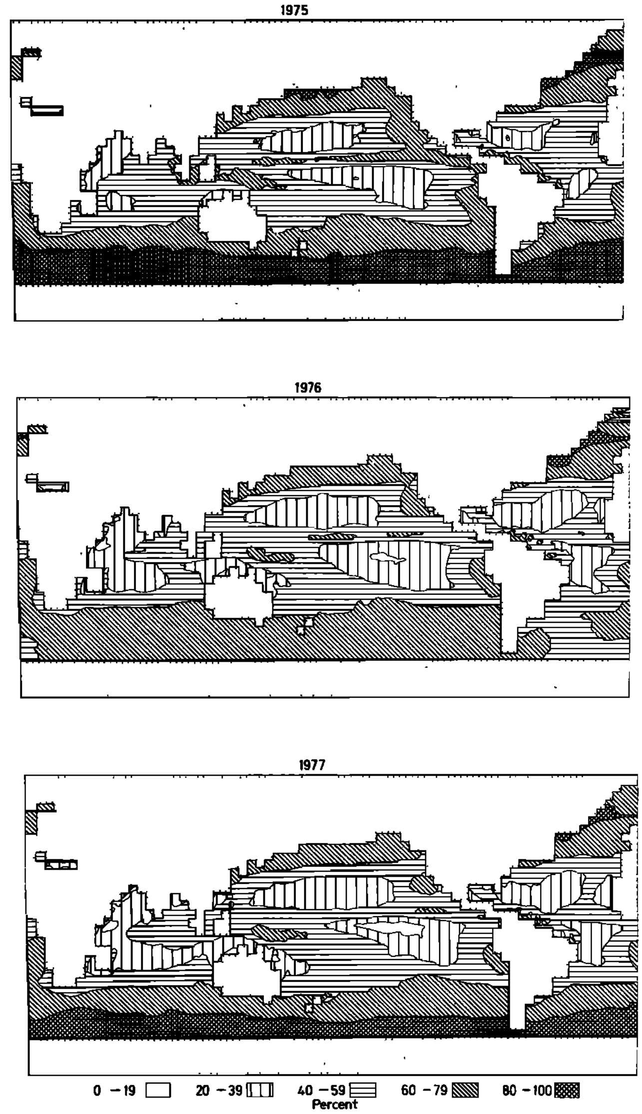

Fig. 5. Calculated global distribution of oceanic annual mean cloud amount for (a) 1975, (b) 1976, (c) 1977.

Similar maps of annual oceanic cloud cover have been produced for the years 1975 and 1976 (Figures 5a and 5b). Owing to erroneous data processing of the ERB data Winston et al.,[1979], the southern hemisphere system albedo data during 1976 are in error. This is the cause of the anomalously low cloud amount shown in Figure 5b. The cloud amounts shown in the high latitude regions within the compass of the marginal sea-ice zone may also be slight overestimates. Although most of the sensitive area has been excluded in Figures 5 and 6, it is possible that outbreaks of sea-ice could be interpreted as cloud. However, as the albedo of sea-ice is much lower than that of snow-covered fast ice, the error is likely to be small. The (Figure 5) maps of oceanic total cloud amount show some small inter-annual variations. The area of lowest cloud amount occurs in

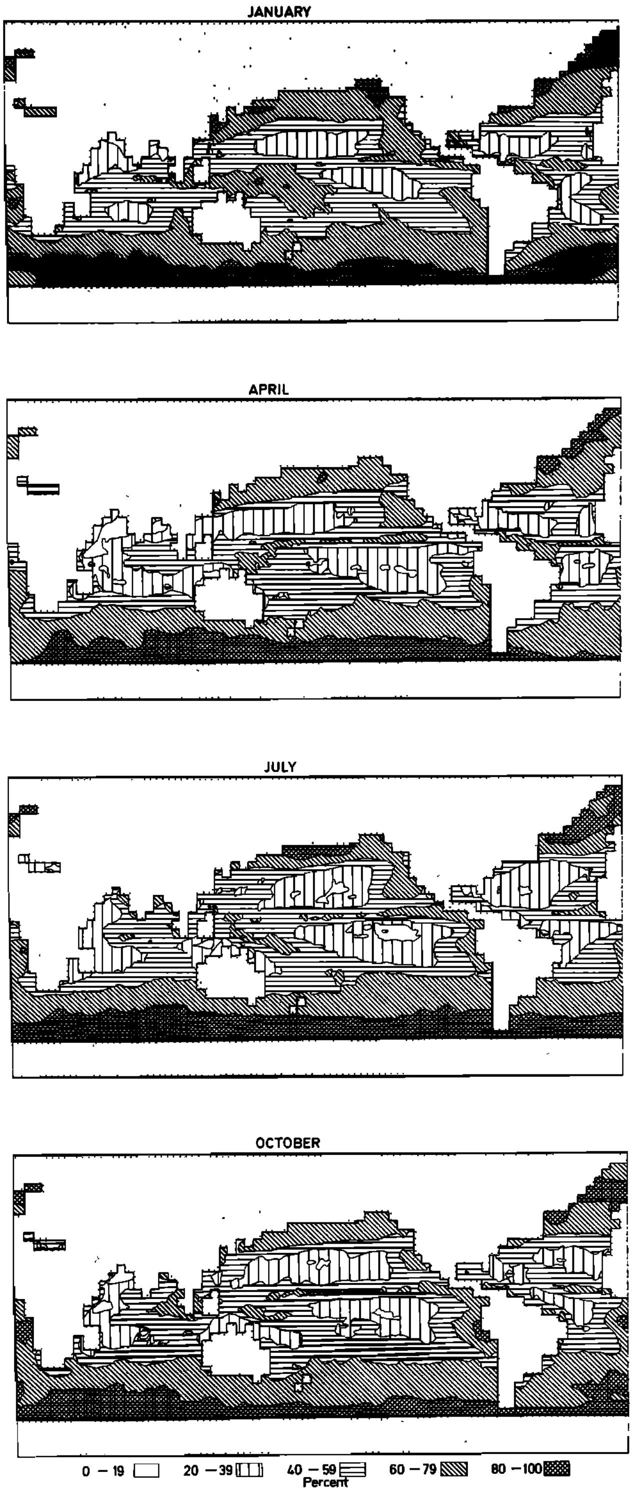

Fig. 6. Calculated global distribution of oceanic monthly mean cloud amounts for (a) January, (b) April, (c) July, (d) October using system albedo data averaged over the years 1975, 1976, 1977.

the Pacific Ocean, south of the equator during all 3 years. The cloud amount over this region decreases steadily from 1975-1977. Similarly, cloud amount also decreases over the Indian Ocean. The magnitude and extent of the equatorial cloud band appears to vary between years (e.g., is less well defined in 1977 than 1975). Maximum cloud amount occurs in the mid-latitudes of both hemispheres in all 3 years showing the predominant path of depression systems.

As was decribed above, estimates of low cloud amount are likely to be more accurate than those of higher percentage cloud amount. This is probably due to the differing effect of cloud type upon the overall reflectivity of the scene. Cloud albedo is also dependent on illumination angle. An identical cloud field in the mid-latitudes and tropics would be expected to have a lower albedo in the tropics (i.e., seasonal changes in system albedo at one location do not necessarily imply changes in cloud cover). The technique presented here does not attempt to incorporate seasonal variations in illumination angle. The relationship between mean monthly system albedo and cloud amount is reasonably seasonally consistent (Figure 3). Thus we suggest that the effect of illumination angle appears to be small.

Maps of global oceanic cloud amount for individual months representative of the four seasons (January, April, June, and October) are presented in Figure 6. These maps represent a 3-year average (1975, 1976, and 1977). The annually averaged maps (Figure 5) are directly comparable with other global cloud climatologies. However, it may be more appropriate to consider the seasonal maps as 'effective' cloud amount. Here, the term 'effective' incorporates the combined impact of cloud amount, type and sun angle on the system albedo. This 'effective' cloud cover can be incorporated into climate models and/or used for reparameterization of cloud prediction schemes when the primary goal is tuning to improve agreement between net flux at the top of the atmosphere and cloud cover [e.g., Meleshko and Wetherald, 1981].

Substantial seasonal variations in effective cloud amount do occur. The near-equatorial cloud band attains its southern-most position in April. Cloudiness minima persist throughout the year in the oceanic areas dominated by the subtropical highs, especially in the North and South Pacific oceans where lowest cloud amount occurs in July. Other areas undegoing considerable seasonal variation occur in the mid-Atlantic Ocean and Indian Ocean. Despite the changes in cloud amount occuring seasonally, the location of the areas of cloudiness minima and maxima remain relatively constant (see also Figure 5).

6. Conclusions

Concurrent 3D-nephanalysis total cloud amount data and ERB system albedo have been used to produce a predictive relationship between system albedo and cloud amount. The data sample available suggests a logarithmic relationship between system albedo and cloud amount over oceans, which varies little with season. This relationship has been examined by using both daily averaged mean monthly cloud amount and 0900 mean monthly cloud amount. Owing to the time lag of information flow into the 3D-nephanalysis archive and the preference for a universally applicable relationship, the mean diurnal cloud amount has been selected for use in the predictive equation. Oceanic global cloud climatologies for 1975, 1976, and 1977 have been produced together with 3 year mean seasonal maps of cloud. The cloud amount distributions compare favorably with accepted cloud climatologies.

It is important to acknowledge that the technique investigated here is appropriate only for areas having low surface albedoes. It would be interesting to extend the predictive relationship to continental vegetated areas. However, in any region where the system albedo is strongly dependent upon the surface reflectivity, a much more detailed approach would be required. The prediction of global cloud cover amounts for oceanic regions is particularly useful since it is for these regions that conventional data are scarce.

This pilot study demonstrates the potential of using independent archived system albedo data to derive oceanic cloud amounts. The predictive relationship derived here could also be applied to other system albedo data sets. In particular it would be especially interesting to construct cloud statistics at higher temporal and spatial resolutions. Such cloud climatologies may be of use in climate modeling studies.

We wish to make it clear that we have intentionally resisted the temptation to make two statements, touched upon here, more positively. We refer to (1) the comparison between the cloud climatologies produced here and other cloud data and (2) the usefulness of cloudiness data for the climate modeling community. It is not at all obvious that cloud information derived from different sources can be usefully compared, and, certainly, any comparisons must be undertaken with caution. In a separate paper we intend to consider both the effects of spatial and temporal sampling and averaging upon cloud statistics. The second point is generic to all current and traditional cloud climatologies since it prejudges an issue not yet explored namely the expected relationship between 'real' cloud fields and those predicted by climate models. Model predicted clouds may be expected to be consistent with the radiation field, whereas only a few current cloud retrieval algorithms derive radiatively consistent cloud information. There is no reason to believe that surface-observed cloud is consistent with the radiation fields at the top of the atmosphere. Point two is clearly one example of the fundamental first point.

Despite all these problems, the continued suggestion that cloud feedback could be an important factor in climate sensitivity experiments [e.g., Meleshko and Wetherald, 1981] forces the scientific community to construct, analyze and compare cloud climatological information.

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References

Avaste, O. A., G. G. Campbell, S. K. Cox, D. DeMasters, O. U. Karner, K. S. Shifrin, E. A. Smith, E. J. Steiner, and T. H. Vonder Haar, On the estimation of cloud-amount distribution above the world oceans, Atmos. Sci. Pap. 309, Colorado State Univ., Fort Collins, Colorado, 1979.

Berlyand, T. G., and L. A. Strokina, Global distribution of total cloud amount, State Committee of the Soviet Union for Hydrometeorology and Control of the Natural Environment, Leningrad, Gidrometeoizdat, 1980.

Clapp, P. F., Global cloud cover for seasons using 'TIROS' nephanalysis, Mon. Weather Rev., 92, 495-507, 1964.

Cogley, J. G., The albedo of water as a function of latitude, Mon. Weather Rev., 107, 775-781, 1979.

Fye, F. K., The AFGWC automated cloud analyses model, Tech. Memo. 78-002, U.S.A.F. Global Weather, Offutt, 1978.

Gordon, A., and R. Hovanec, The sensitivity of model-derived radiation fluxes to the monthly mean specification of cloudiness, in Clouds in Climate, Goddard Institute for Space Studies, NASA, New York, October 29-31, 1981.

Hartmann, D. L., and D. A. Short, On the use of earth radiation budget statistics for studies of clouds and climate, J. Atmos. Sci., 37, 1233-1250, 1980.

Hastenrath, S. and P. J. Lamb, Climate Atlas of the Tropical Atlantic and Eastern Pacific Oceans, The University of Wisconsin Press, Madison, 1977.

Henderson-Sellers, A., N. A. Hughes, and M. F. Wilson, Cloud cover archiving on a global scale: A discussion of principles, Bull. Am. Meteorol. Soc. 62, 1300-1307, 1981.

Hummel, J. R., and R. A. Reck, A global surface albedo model, J. Appl. Meteorol., 18, 239-253, 1979.

London, J., A study of the atmospheric heat balance, Report, Coll. of Eng., New York Univ., New York, 1957.

Meleshko, V. P., and R. T. Wetherald, The effect of a geographical cloud distribution on climate: A numerical experiment with an atmospheric general circulation model, J. Geophys. Res., 86, 11995-12014, 1981.

Miller, D. B., and R. G. Feddes, Global Atlas of Relative Cloud Cover 1967-70, U.S. Dept. of Commerce, Air Weather Service, E.T.A.C., Washington, D.C., 1971.

Ohring, G., and P. F. Clapp, The effect of changes in cloud amount on the net radiation at the top of the atmosphere, J. Atmos. Sci., 37, 447-454, 1980.

Ohring, G., P. Clapp, T. R. Heddinghaus, and A. F. Krueger, The quasi-global distribution of the sensitivity of the earth-atmosphere radiation budget to clouds, J. Atmos. Sci., 38, 2539-2541, 1981.

Sadler, J. C., Average Cloudiness in the Tropics from Satellite Observations, East-West Center Press, Honolulu, Hawaii, 1969.

Schneider, S. H., Cloudiness as a global climatic feedback mechanism: The effects on the radiation balance and surface temperature of variations in cloudiness, J. Atmos. Sci., 39, 1413-1433, 1972.

Stephens, G. L., G. W. Paltridge, and C. M. R. Platt, Radiation profiles in extended water clouds, 3, Observations, J. Atmos. Sci., 35, 2133-2141, 1978.

Wanless, N., Cloud climatology as an analytic and predictive tool, B.Sc. Thesis, Geography Dep., Liverpool Univ., 1979.

Winston, J. A., A. Gruber, T. I. Gray, M. S. Varnadore, C. L. Earnest, and L. P. Mannello, Earth-Atmosphere Radiation Budget Analyses Derived From NOAA Satellite Data June 1974 to February 1978, vol. 1 and 2, NOAA/NESS, Washington, D.C., 1979.

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